INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
ISSN: 2180-3242 e-ISSN: 2600-7959

IJSCET

Vol. 16 No. 1 (2025) 179-192
https://publisher.uthm.edu.my/ojs/index.php/ijscet

Integrating Technology for Construction Site Safety Management (CSSM) in Pakistan: Challenges and Ways Forward

Samiullah Sohu[1], Tahara Ramadzan Md Kassim[2]*

[1] *Department of Civil Engineering,*
The University of Larkano, 77150, PAKISTAN
[2] *Department of Civil Engineering,*
International Islamic University Malaysia, 53100, MALAYSIA

*Corresponding Author: tahara@iium.edu.my
DOI: https://doi.org/10.30880/ijscet.2025.16.01.015

Article Info

Received: 5 March 2025
Accepted: 18 June 2025
Available online: 30 June 2025

Keywords

Integration, safety management, challanges, construction industry, Pakistan

Abstract

Construction in Pakistan remains one of the most hazardous sectors globally, with persistent safety lapses and slow adoption of modern technologies. This study investigates the obstacles preventing effective integration of technology into Construction Site Safety Management (CSSM). Despite global progress in CSSM technologies like IoT, BIM, AR/VR, and AI, Pakistani construction sites largely depend on manual safety practices. This results in low efficiency and increased workplace hazards. The primary objective is to identify and major barriers to integrating technology in CSSM within Pakistan and propose practical, context-sensitive solutions for advancing safety protocols. Adopting a sequential explanatory design, the research began with a quantitative survey of Pakistani construction professionals to rank challenges in technology adoption. Following the survey, qualitative interviews were conducted with industry experts to delve deeper into these barriers and explore feasible solutions. Quantitative insights helped shape the qualitative discussions, leading to evidence-based recommendations. The results of the study identified key challenges to technology integration in CSSM, including costly setups, financial limitations, and a significant gap in research and development. Experts suggests potential solutions such as establishing public-private partnerships, initiating modular technological implementations, and setting up dedicated research centers to address these challenges. This finding provide effective recommendations for stakeholders in Pakistan's construction industry to enhance safety practices through the strategic integration of technology. The proposed solutions offer a roadmap for overcoming financial and research-related challenges, thereby improving occupational safety standards mainly in the construction industry.

1. Introduction

Construction industry in Pakistan has experienced remarkable growth and development over the past few decades, driven by a burgeoning population and the increasing demand for infrastructure [1]. As this industry expands, it faces a myriad of challenges, with one of the most aspect is safety management [2]. Safety in construction is a paramount concern, given the inherent hazards associated with heavy machinery, elevated

workspaces, and complex projects. Ensuring the safety of workers, contractors, and the public is crucial for the industry's sustainable growth. In this context, the integration of technology into safety management practices seems to be proactively reducing risks and enhancing overall safety performance.

In the global perspective on construction safety, statistics revealed an alarming annual tally of over 60,000 fatalities in construction projects worldwide, with developed countries, such as those in Europe, accounting for a significant portion [3]. Therefore, there is the need for further investigation into safety management aspects within construction projects to reduce fatalities and injuries. The rapid advancement of digital technologies has led to their increased integration into construction projects, primarily due to the advantages they offer in improving safety conditions. A growing trend is noted in research efforts aimed at harnessing digital technologies, including virtual reality, mixed reality, digital twins, and the Internet of Things (IoT), to enhance construction project safety [4]. IoT, in particular, stands out as a valuable tool for automating safety monitoring and hazard detection at construction sites. To fully leverage the potential of digital technologies, these devices must be interconnected, enabling seamless data transfer and analysis by experts.

While the literature extensively highlights the advantages of technology integration for CSSM, the adoption of technology remains in its infancy, even in developed nations Pakistan's construction industry has experienced remarkable growth over the past few decades, fueled by a rapidly expanding population and increasing demand for infrastructure contributing around 2.5% of GDP and employing roughly 7 million workers. As the sector scales, safety management remains a paramount concern due to inherent hazards associated with heavy machinery, elevated workspaces, and project complexity. While integrating advanced technologies like IoT devices, BIM, drones, wearable sensors, and AI has the potential to proactively reduce risks and improve occupational safety performance, a significant research gap persists in comprehensively analyzing the challenges impeding widespread adoption of such technologies. To address this gap, this study aims to identify the key challenges hindering the integration of technology into Construction Site Safety Management (CSSM) in Sindh's construction industry. The study first evaluates the major challenges facing construction firms in adopting safety technologies, then offers evidence-based strategies for effective implementation. This study determined the combination of site safety management theories, technology adoption models, and socio-economic perspectives with the integration of technology of Construction Site Safety Management (CSSM) in Sindh, Pakistan. These theoretical underpinnings help to explain the barriers to technological implementation and inform potential strategies for overcoming them.

1.1 Safety Management Theories

One of the key theoretical approaches of safety management is Behavioral-Based Safety (BBS), which focuses on the role of worker behavior in accident prevention. BBS posits that unsafe behavior is the primary cause of accidents, and interventions targeting behavior can effectively reduce risks [5]. Technological tools such as real-time monitoring systems and wearable devices can support BBS by providing feedback to workers, thereby influencing their behavior towards safer practices. In the context of Sindh's construction industry, these technologies could play a critical role in addressing the prevalent safety issues by mitigating unsafe behaviors.

Another relevant theory is the Systems Theory of Safety Management (STSM), which views safety as an outcome of the interactions between various components within a system, including people, processes, and technology [6]. This theory supports the integration of technology as a means to enhance overall safety by improving the coordination and control of various safety-related processes on construction sites. For example, the use of drones for site monitoring and artificial intelligence for hazard prediction can strengthen the entire safety management system.

1.2 Socio-Economic Perspective

The Resource-Based View (RBV) provides another theoretical dimension, focusing on the importance of organizational resources in achieving a competitive advantage [7]. From the perspective of CSSM, these resources include financial investment, technical expertise, and access to innovative technologies. The availability and strategic use of these resources are critical for the successful implementation of safety technologies in Sindh's construction industry, where financial constraints and limited technical knowledge have been identified as significant barriers [8].

Additionally, Public-Private Partnership (PPP) Theory is relevant to understanding how collaborative efforts between the public and private sectors can alleviate some of the economic and infrastructural challenges that hinder technological adoption. PPPs have been recognized as an effective mechanism for overcoming financial barriers by pooling resources and expertise [9]. In the case of Sindh, Pakistan public-private partnerships could facilitate the establishment of research centres and modular technology implementations, thereby reducing the financial burden on individual construction firms.

1.3 Contextual Factors in Sindh

Incorporating the socio-cultural and economic realities in Sindh is critical to understanding the challenges of technology adoption in CSSM. The construction industry in Sindh is characterized by low levels of literacy and resistance to change, which can impede the adoption of new technologies. To address these challenges, training programs tailored to the local workforce's needs and the development of culturally appropriate instructional materials are necessary [10].

Economic constraints are another significant factor limiting technology adoption in the region. The construction sector in Sindh faces limited investment in safety infrastructure, and many firms operate on tight budgets. Modular technological solutions that can be implemented incrementally may help to mitigate the cost burden [11]. Additionally, dedicated research centers focused on construction safety in Pakistan could bridge the existing research gaps and provide context-specific solutions for the industry.

By drawing on these theoretical perspectives, this study provides a comprehensive framework to understanding the integration of technology into CSSM in Sindh. Safety management theories highlight the potential impact of technology on worker behavior and system-wide safety improvements. Meanwhile, technology adoption models and socio-economic perspectives help to identify the key barriers to implementation and propose strategies for overcoming these challenges. This theoretical framework underpins current study's sequential explanatory design, by using both quantitative and qualitative data to develop effective recommendations for enhancing safety management practices in Sindh's construction industry.

2. Research Gap and Knowledge

While the literature provides valuable insights into various aspects of construction safety and technology integration, there is a noticeable gap in addressing the specific challenges faced by developing countries, such as Pakistan. The literature has yet to fully explore the holistic integration of technology, including IoT and RTLS, to enhance safety practices in these contexts. Additionally, there is limited research to bridge these gaps and develop comprehensive strategies for enhancing safety in developing countries' construction industries. Table 1 shows the challenges using integration of technology for CSSM.

Table 1 *Mapping of challenges in the integration of technology for CSSM*

Challenges	Challenge Description	References
Traditional Resistance	Resistance to change from traditional practices	[12]
Financial Constraints	Inadequate financial resources for technology investments	[13]
Remote Connectivity	Limited access to reliable internet in remote sites	[14]
Cloud Security	Data security concerns in cloud-based solutions	[15], [16]
Tech Compatibility	Compatibility issues between different technology systems	[11], [17]
Skilled Shortage	Shortage of skilled personnel for technology operation	[18], [19], [20]
Power Interruptions	Power outages and electrical supply issues	[21], [22]
Costly Setup	Costly initial setup and infrastructure requirements	[23], [24]
Regulation Gaps	Inadequate government regulations and standards	[25]
Local Support	Lack of local technical support and maintenance services	[26]
Contractor Incentives	Lack of incentives for contractors to invest in tech	[27], [28]
Supply Chain	Complex supply chain issues for tech components	[29], [30]
Financing Options	Limited access to financing options for tech integration	[31], [32]
Compliance Hurdles	Compliance challenges with international standards	[33], [34], [35]
Harsh Environments	Difficulty in maintaining tech in harsh environments	[36], [37]
AI Ethics	Ethical dilemmas related to AI safety decision-making	[38]
BIM Adoption	Limited use of Building Information Modeling (BIM) for safety	[39], [40], [41]
Tech Reliance	Low reliance on the technology	[42]
Retrofitting Difficulty	Difficulty in retrofitting older machinery with safety tech	[43]
R&D Gaps	Inadequate research and development in local safety tech	[3], [44]
Backup Plans	Inadequate backup and recovery plans for tech failures	[22]

3. Methodology

The study employed a two-phase mixed-method approach. In the first phase, quantitative data was collected to assess the extent and severity of challenges associated with the integration of technology in Construction Site Safety Management (CSSM). This phase helped identify the most frequently encountered and critical challenges as perceived by industry professionals. In the second phase, qualitative data was gathered to gain deeper insights into these challenges and to explore practical strategies for overcoming them. This sequential mixed-method design ensured a comprehensive understanding of both the issues and potential solutions. For the quantitative analysis, mean scores for each challenge were calculated using SPSS. For the qualitative phase, content analysis was conducted to highlight relevant strategies for addressing the identified challenges. The qualitative findings built upon the quantitative results, offering contextual depth and supporting the development of targeted strategies for enhancing technology integration in CSSM. Figure 1 shows the flow of methodology adopted for this research.

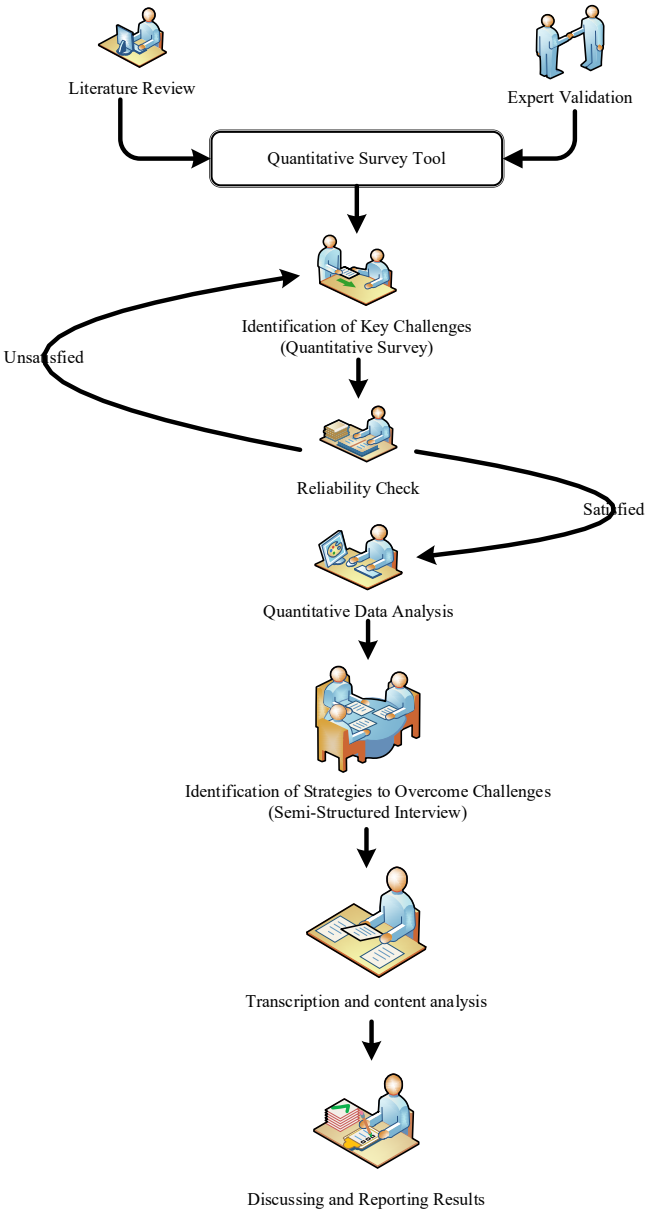

Fig. 1 *Research flowchart*

3.1 Selection of Respondents

The study employed purposive sampling techniques to ensure practical results. The target was to select respondents with both relevant experience in Pakistan's construction industry and expertise in technology integration for safety. To identify qualified respondents for data collection, the selection criteria suggested by in

Durdyev et al., (2022) and Jin et al., (2019) was adopted. Eligible respondents were required to hold at least an undergraduate degree in fields such as civil engineering, construction management, construction safety, planning and development, or building construction. This criterion was important to ensure that the respondent possessed the technical knowledge for understanding building projects. Additionally, respondents should have a minimum of five years of experience in construction safety, actively involved in supervisory, managerial, or operational roles, and overseeing safety operations on construction sites. This guaranteed they had first-hand experience in the technical aspects that relevant to this study. Applying these criteria led to the selection of 30 experts for the quantitative survey and 4 experts for the qualitative survey [47]. The demographic details of the respondents are illustrated in Table 2.

Table 2 *Demography of respondents*

	SN.	Designation	Participant	Experience (Years)				Qualification		
				6-10	11-15	16-20	21-25	PhD	M.E	B.E
Quantitative	1	Director Works and Services	02			1	1	1		1
	2	Project Director	05		3	2			3	2
	3	Deputy Director (P&D)	04	3	1				1	3
	4	Project Manager	07	3	4				2	5
	5	Assistant Engineer	06	4	2				3	3
	6	HSE Engineer	06	1	5					6
	SN.	Designation	Participant	Experience (Years)				Qualification		
Qualitative				6-10	11-15	16-20	21-25	PhD	M.E	B.E
	1	Director Works and Services	02			1	1	1		1
	2	Project Director	02			2			2	

3.2 Data Collection Tools

A data collection tool is a device, instrument, or methodology used to gather data in research studies. It enables researchers to collect, record, and analyze data from participants, observations, or existing documents [48]. In this study, two data collection tools were utilized; a structured questionnaire survey for quantitative data collection and an unstructured interview guide for qualitative data collection. A questionnaire is a structured tool used to collect self-reported data through a series of questions [48]. It is a widely used quantitative data collection tool, particularly in surveys and studies involving large samples. However, an interview guide is a structured document that outlines the topics, questions, and probes to be used during an in-depth interview [48]. It serves as a roadmap for the interviewer, ensuring that all essential topics are covered and allowing for flexibility in exploring new ideas.

3.3 Development of Quantitative Tools

To identify challenges in the integration of technology in construction site safety management, a two-step approach was undertaken. First, a comprehensive literature review was conducted to identify challenges related to technology integration in CSSM. Next, the identified challenges were validated by 4 experts., comprising 3 field experts and 1 language expert. The field experts validated the questionnaire's content, while the language experts looked for clarity of expression. The experts were also asked to suggest any additional challenges not found in the literature or identify any overlooked challenges. However, all experts unanimously agreed that the identified challenges covered all aspects of the current state of the industry, and no changes were made at this stage. This two-step approach led to the identification of a total of 21 challenges, which were incorporated into a questionnaire design.

The questionnaire consisted of two sections: Section A gathered demographic information about the respondents, while Section B focused on identifying key challenges impeding the adoption of technology of CSSM in Pakistan's construction industry. Respondents were asked to mark their responses on a 5-point Likert scale, ranging from strongly agree (5) to strongly disagree (1). To assess the internal consistency of the data, a reliability test was conducted using a sample of 30 respondents. According to Adeyemi (2024), a reliability test measures the coherence and dependability of collected data. In this study, Cronbach's alpha was used to assess the reliability of the questionnaire, as it is the most widely used indicator for internal consistency [49]. Cronbach's alpha values range from 0 to 1.00, with values near 1.00 indicating good consistency. Values greater than 0.7 are considered

acceptable, while values lower than 0.3 are not [49]. The Cronbach's alpha coefficient for this study was 0.83, which falls within the acceptable range, suggesting that the data collected using the tool was reliable.

3.4 Development of Quantitative Tools

For the qualitative component of this study, an interview guide was developed as the primary data collection tool. The development of the interview guide followed the guidelines suggested by Rose and Johnson, (2020). These guidelines emphasized the importance of clearly identifying key questions to be addressed through the interview, based on the research objectives. To develop the interview guide, a framework was established, comprising an introduction, background questions, open-ended questions, and follow-up questions. This framework was designed to facilitate in-depth exploration of the research topic and gather detailed information from participants.

Prior to finalizing the interview guide, a pilot test was conducted with a small group of participants to ensure that the questions were clear, relevant, and effective [50]. This pilot test provided valuable feedback, which was used to refine the interview guide and ensure its contextual relevance. Following the completion of these steps, a finalized interview guide was developed. This guide was refined, contextually relevant, and had the potential to provide possible strategies for addressing challenges related to technology integration in Construction Site Safety Management (CSSM)

3.5 Data Collection

The questionnaire for collection of data was based on the literature review in accordance with the objectives of the study. The survey was carried out by mail, email and in person meetings with the qualified experts. The questionnaire-based survey was used to elicit the perception of construction and safety professionals towards challenges in the integration of technology for CSSM.

Qualitative data was collected through semi-structured interviews conducted, each interview session lasted approximately 20 minutes and was audio-recorded with the participants' consent. Interviews were guided by a set of open-ended questions designed to explore participants' experiences and perceptions related to strategies to overcome challenges in integrating technology for construction site safety management in the Pakistani Construction industry.

3.6 Data Analysis

The data analysis of a Sequential explanatory-based study is particularly valuable when dealing with complex, multifaceted datasets that require a deeper understanding [48]. It allows researchers to go beyond the numbers and uncover the underlying stories and reasons behind the data, ultimately leading to more informed decision-making and actionable insights. As the study involved a quantitative and qualitative approach therefore different methods were used for the analysis of quantitative and qualitative data.

Quantitative: For the analysis of quantitative data, the data was analyzed in SPSS to identify the mean and standard deviation of each challenge in integrating technology. Out of 21 challenges, three were selected as the key challenges in integrating technology into site safety management in Pakistan’s construction industry. The key challenges were selected based on having a mean value between 4 and 5, and as per the mean range criteria by Hassan et al., (2020) and Sohu et al., (2018) factors having a mean of 4 to 5 are considered significant.

Qualitative: Content analysis was chosen as the method for data analysis due to its flexibility and suitability for identifying key contents within qualitative data. All interview recordings were transcribed. The coding process was conducted manually. Two researchers independently coded the transcripts, allowing strategies to emerge directly from the data. After initial coding of a subset of transcripts, the researchers met to discuss and refine the strategies. This iterative process continued until saturation was reached and no new strategies from the experts were identified.

4. Finding and Analysis

The initial part of this section presents descriptive statistics results, providing a comprehensive overview of respondents' perceptions on the prevalence of various challenges related to integrating technology for CSSM. The subsequent part presents expert opinions from semi-structured interviews, outlining strategies to address these challenges and enhance technology integration in the construction industry. The Table 3 summarizes the mean values for each challenge identified from the literature.

Int. J. of Sustainable Construction Engineering and Tech. Vol. 16 No. 1 (2025) p. 179-192

Table 3 *Results of quantitative survey*

Rank	Challenge	Mean	Std. Deviation
01	Costly Setup	4.4667	.50742
02	Financial Constraints	4.2000	.66436
03	R&D Gaps	4.1333	.62881
04	Power Interruptions	3.9000	.60743
05	Skilled Shortage	3.8000	.40684
06	Regulation Gaps	3.7000	.59596
07	Traditional Resistance	3.6667	.71116
08	Financing Options	3.6333	.66868
09	Remote Connectivity	3.6000	.62146
10	BIM Adoption	3.5333	.62881
11	AI Ethics	3.4000	.49827
12	Tech Reliance	3.3667	.66868
13	Tech Compatibility	3.2667	.69149
14	Backup Plans	3.2333	.62606
15	Local Support	3.2333	.67891
16	Compliance Hurdles	3.1000	.40258
17	Cloud Security	3.1000	.30513
18	Supply Chain	2.8667	.68145
19	Contractor Incentives	2.7333	.44978
20	Harsh Environments	2.6667	.95893
21	Retrofitting Difficulty	2.6333	.66868

It is evident from the descriptive statistics that "Costly Setup" is perceived as one of the most dominant challenges (Mean = 4.4667), followed closely by "Financial Constraints" (Mean = 4.2000) and "R&D Gaps" (Mean = 4.1333). These statistics provide a preliminary understanding of the challenges that appear in integrating technology for CSSM as perceived by the professionals of the construction industry. It is important to note that mean values ranging from 4 to 5 are considered as dominant challenges following the criteria suggested by [51] within the context of this study.

These dominant challenges demand strategic planning and solutions to facilitate the successful integration of technology in CSSM practices. The subsequent section explores deeper into the study and explores the strategies to address these challenges effectively for the industry's progression towards technological integration for CSSM.

4.1 Challenge 1: Costly Setup

Experts suggested overcoming the challenge of a costly setup when integrating technology for CSSM in the Pakistani construction industry requires a well-thought-out approach. Experts have provided a range of strategic recommendations to address the challenge of the costly setup in integrating technology for CSSM. These suggestions include conducting a cost-benefit analysis to demonstrate the long-term advantages of technology adoption, seeking government incentives and grants, collaborating with industry associations and trade organizations for financial support, opting for scalable and modular solutions for gradual implementation, considering leasing or renting technology equipment, and developing a comprehensive, multi-year technology adoption plan. Additionally, experts emphasize exploring partnerships with private entities interested in enhancing construction safety. By strategically implementing these approaches, the construction industry in Pakistan can effectively tackle the financial barriers associated with technology integration for improved safety management on construction sites. Table 4 showed the excerpts regarding the strategies to overcome the challenge of Costly Setup.

Table 4 *Excerpts regarding the strategies to overcome the challenge of costly setup*

Excerpt	Suggested by
Cost-benefit analysis to justify the investment in technology This analysis can help in convincing stakeholders of the long-term benefits of the technology	Expert 1
Apply for government incentives, grants, or subsidies available for adopting safety technology in the construction industry.	Expert 2
Partner with construction industry associations and trade organizations that may have resources or funding opportunities for safety technology adoption.	Expert 2
Start with scalable and modular solutions that allow for gradual implementation.	Expert 1
Consider leasing or renting the necessary safety technology equipment rather than purchasing it outright.	Expert 1
Develop a long-term technology adoption plan that spans several years. This allows for better budgeting and ensures that technology integration is sustainable and aligns with the organization's financial capabilities.	Expert 2
Explore partnerships with private companies or organizations that have an interest in improving safety in the construction industry.	Expert 1 and 2
By strategically planning and considering these approaches, you can work towards overcoming the challenge of a costly setup when integrating technology for construction site safety management in the Pakistani construction industry.	Expert 1

4.2 Challenge 2: Financial Constraints

The experts have put forth several strategies to address the challenge of financial constraints when integrating technology for CSSM. First, they suggest educating stakeholders about the long-term benefits of improved safety, emphasizing reduced accident-related costs, diminished legal liabilities, and improved project timelines. This approach aims to shift the perception of safety from an expense to a valuable investment. Additionally, experts propose that governments play a crucial role by creating comprehensive safety plans outlining necessary technologies and expected return on investment (ROI). Exploring financing options like loans, leases, or partnerships with technology providers is another avenue recommended by experts. To mitigate initial costs, experts advocate starting with pilot projects or limited technology implementations to demonstrate effectiveness. Lastly, they stress the importance of continuously improving safety measures and technologies, underscoring the dynamic nature of CSSM. Remember that safety is not just a legal requirement but also a moral obligation. By demonstrating a commitment to safety, you may also enhance your company's reputation, which can attract more clients and opportunities for growth in the long run. Table 5 presented the excerpts regarding the strategies to overcome the challenge of Financial Constraint.

Table 5 *Excerpts regarding the strategies to overcome the challenge of financial constraints*

Excerpt	Suggested by
Educate stakeholders about the long-term benefits of improved safety, including reduced accident-related costs, legal liabilities, and improved project timelines.	Expert 2
Convince them that safety is an investment, not just an expense.	Expert 1
Government should create a comprehensive safety plan that outlines the specific technologies needed and the expected return on investment (ROI).	Expert 1 and 3
Investigate financing options such as loans, leases, or partnerships with technology providers.	Expert 1 and 3
Begin with a pilot project or a limited implementation of safety technology to show its effectiveness.	Expert 1 and 4
Emphasize the continuous improvement of safety measures and technologies.	Expert 4 and 2

4.3 Challenge 3: Research and Development Gaps

In addressing the challenge of research and development gaps in integrating technology for CSSM within the Pakistani construction industry, a comprehensive approach is essential. The experts have proposed several strategies to tackle this issue. First, fostering collaboration among construction companies, government bodies,

and academic institutions is crucial to bridging these gaps. The establishment of research centers and consortiums dedicated to construction safety technology can facilitate this collaboration. Allocating resources and funding specifically for research and development initiatives in safety technology is another key step, with support from both the private sector and government grants. Encouraging a culture of research and innovation within construction companies by incentivizing employees to engage in safety technology research is vital. Furthermore, technology incubators and accelerators focused on construction safety technology can also nurture innovation. To educate professionals and workers, training programs and workshops should be developed. Lastly, showcasing successful safety technology implementations through case studies and live demonstrations can inspire confidence and adoption in the industry. These strategies, when implemented collectively, can significantly contribute to overcoming research and development gaps and promoting the effective integration of technology for CSSM in Pakistan as shown in Table 6.

Table 6 *Excerpts regarding the strategies to overcome challenges of research and development gaps*

Excerpt	Suggested by
Foster collaboration between construction companies, government bodies, and academic institutions to bridge the research and development gaps.	Expert 1
Establishing research centers or consortiums focused on construction safety technology.	Expert 1
Allocate resources and funding for research and development initiatives specifically geared towards construction safety technology	Expert 2
Encourage private sector investment & government grants to support innovation in this area.	Expert 1 and 2
Encourage a culture of research and innovation within construction companies by providing incentives for employees to engage in research projects related to safety technology.	Expert 1 and 2
Establish technology incubators and accelerators focused on construction safety technology.	Expert 1 and 2
Develop training programs and workshops that educate construction professionals, engineers, and workers about the importance and implementation of safety technologies.	Expert 2
Showcase successful implementations of safety technology in construction projects through case studies and live demonstrations.	Expert 1 and 2

5. Discussion

The insights garnered from the questionnaire survey and the interviews with experts shed light on several challenges within the Pakistani construction industry, including costly setup, financial constraints, and research and development gaps when integrating technology for CSSM. When analyzed in the context of the existing literature, these challenges appear to be universal, faced not only in Pakistan but also globally [1], [29], [52].

Costly setup, as illuminated by expert interviews, is a significant hurdle in adopting technology for construction site safety. This challenge is not unique to Pakistan, as it resonates with research from other regions [53]. To address this issue, experts' recommendations align with the existing literature, emphasizing the need for a well-planned and strategic approach, for example critical path method (CPM) [54]. This includes conducting cost-benefit analyses, seeking government incentives, and collaborating with industry associations and trade organizations for financial support. The notion of scalable and modular solutions, e.g., industrialized building systems and partnerships with private entities, also mirrors the idea of phased technology integration and public-private collaboration found in the literature [17]. Together, these expert suggestions offer a comprehensive and research-backed strategy to tackle the financial challenges associated with technology adoption for construction safety not only in Pakistan but also beyond.

The interviews also shed light on the challenge of financial constraints in adopting safety technology, with recommendations that echo findings from the existing literature. Strategies include educating stakeholders about the long-term benefits of safety investments and exploring financing options like loans, leases, or partnerships with technology providers [55]. Starting with pilot projects and emphasizing continuous improvement in safety measures aligns with a phased approach to technology adoption and the dynamic nature of construction site safety (e.g. building information modelling) discussed in the literature. Additionally, the ethical dimension of safety, as emphasized by the experts, finds support in the literature, highlighting how a commitment to safety can enhance a company's reputation and create growth opportunities [56]. The multifaceted benefits of investing in technology

for CSSM are well-documented, and the experts' strategies offer a comprehensive roadmap to overcome financial constraints.

Finally, expert interviews revealed research and development gaps in integrating safety technology into the construction industry. These gaps have the potential to jeopardize worker safety and hinder industry progress, as highlighted in the literature [56], [57]. To bridge these gaps effectively, collaborative efforts among construction companies, government bodies, and academic institutions are essential, as previously suggested in research. The establishment of research centres and consortiums, supported by private and government funding, fosters collaboration and knowledge exchange [58]. Encouraging a culture of research and innovation within construction companies, as emphasized by experts, aligns with literature underscoring the importance of an innovative mindset.

In addition, technology incubators, training programs, and case studies, as recommended by experts, correspond with the literature's emphasis on nurturing innovation, equipping the industry with knowledge and skills, and showcasing successful implementations. This holistic approach not only addresses the specific challenges discussed in the interviews but also underscores the interconnectedness of these challenges and the need for multifaceted solutions.

6. Conclusion and Recommendation for Future Studies

In conclusion, this research study has successfully achieved its primary objectives of identifying key challenges in the integration of technology for CSSM within the construction industry of Sindh, Pakistan, and addressed strategies for overcoming these challenges. The findings from the comprehensive literature review and the content analysis of expert interviews have shed light on the pressing issues facing the integration of technology in CSSM. The findings of the study revealed that the most critical challenge in integrating safety technology in the construction industry was the costly setup, with the highest mean score, followed by financial constraints and research and development (R&D) gaps. Quantitative results confirmed these as key barriers, while qualitative insights provided practical strategies to overcome them. Experts emphasized conducting cost-benefit analyses, leveraging government incentives, and adopting scalable solutions to address setup costs. To mitigate financial constraints, stakeholders should be educated on safety's long-term value, and alternative financing mechanisms should be explored. Bridging R&D gaps requires fostering industry-academia collaboration, investing in innovation, and building a culture that supports safety-related research.

It is evident that the construction industry in Sindh, Pakistan, can benefit greatly from adopting a proactive approach to overcome these challenges. By implementing the strategies recommended in this research, stakeholders in the industry can pave the way for more efficient, safer, and technologically advanced CSSM practices. The CSSM can potentially reduce on-site accidents through the use of real-time monitoring tools, safety sensors, and digital training platforms [59]. It can enhance safety compliance, owing to automated reporting, checklists, and mobile safety applications [60, 61]. This study contributes to the growing body of knowledge on CSSM and provides a valuable resource for decision-makers, industry professionals, and researchers seeking to enhance construction safety in the region. The findings underscore the importance of staying adaptable and innovative in the ever-evolving landscape of construction technology and safety management.

The implementation of the recommendations in real-world situations might be the subject of further studies in the area of CSSM. Research may focus on case studies and real-world applications to assess the effectiveness and challenges associated with partnerships, financial investments, modular solutions, strategic planning, and stakeholder education in the specific context of the construction industry in Sindh, Pakistan. Additionally, investigations into emerging technologies and their integration into CSSM, such as the use of drones, AI, or IoT devices, could provide valuable insights into further improving safety practices. Furthermore, comparative studies between different regions or countries could shed light on the transferability of these strategies to diverse construction environments, enabling a broader and more comprehensive understanding of CSSM enhancement. Integrating technology for Construction Site Safety Management (CSSM) in Pakistan presents numerous advantages, but also comes with challenges that need to be addressed

Acknowledgement

The authors would like to express their sincere appreciation to all individuals and organizations that offered support and assistance throughout the course of this research. Special thanks are extended to the construction professionals, project managers, and stakeholders who kindly shared their experiences and insights. Their valuable contributions were essential to the successful completion of this study.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***Study conception and design:*** *Samiullah Sohu, Tahara Ramadzan Md Kassim;* ***Data collection:*** *Samiullah Sohu, Tahara Ramadzan Md Kassim;* ***Analysis and interpretation of results:*** *Samiullah Sohu, Tahara Ramadzan Md Kassim;* ***Draft manuscript preparation:*** *Samiullah Sohu, Tahara Ramadzan Md Kassim. both authors reviewed the results and approved the final version of the manuscript.*

References

[1] S. M. Ahmed and N. C. Greenville, "A strategic framework to improve construction safety practices in Pakistan," in *Proceedings of the International Conference, Safety, Construction Engineering & Project Management (ICSCEPM*, 2013. Accessed: Aug. 15, 2024. [Online]. Available: https://www.researchgate.net/profile/Zia-Din/publication/328562869_ICSCEPM2013_Proceedings/links/5bd4bb6f4585150b2b8b2b67/ICSCEPM2013-Proceedings.pdf#page=20

[2] R. M. Choudhry, D. Fang, and S. Rowlinson, "Challenging and Enforcing Safety Management in Developing Countries: A Strategy," *Int. J. Constr. Manag.*, vol. 8, no. 1, pp. 87–101, Jan. 2008, doi: 10.1080/15623599.2008.10773110.

[3] K. D. Hampson, J. A. Kraatz, and A. X. Sanchez, "The global construction industry and R&D," in *R&D investment and impact in the global construction industry*, Routledge, 2014, pp. 4–23. Accessed: Aug. 15, 2024. [Online]. Available: https://www.taylorfrancis.com/chapters/edit/10.4324/9781315774916-2/global-construction-industry-keith-hampson-judy-kraatz-adriana-sanchez

[4] F. Luo, R. Y. M. Li, M. J. C. Crabbe, and R. Pu, "Economic development and construction safety research: A bibliometrics approach," *Saf. Sci.*, vol. 145, p. 105519, 2022.

[5] B. P. Yadav, N. Verma, A. K. Mishra, N. A. Siddiqui, and D. Gill, "Usage of Behavioral-Based Safety Approach for Improving Worker Performances in Construction Sector: A Review," in *Advances in Behavioral Based Safety*, N. A. Siddiqui, F. Khan, S. M. Tauseef, W. S. Ghanem, and V. Garaniya, Eds., Singapore: Springer Nature Singapore, 2022, pp. 307–318. doi: 10.1007/978-981-16-8270-4_23.

[6] M. Sony and S. Naik, "Industry 4.0 integration with socio-technical systems theory: A systematic review and proposed theoretical model," *Technol. Soc.*, vol. 61, p. 101248, 2020.

[7] B. Nayak, S. S. Bhattacharyya, and B. Krishnamoorthy, "Integrating the dialectic perspectives of resource-based view and industrial organization theory for competitive advantage–a review and research agenda," *J. Bus. Ind. Mark.*, vol. 38, no. 3, pp. 656–679, 2023.

[8] J. Tamošaitienė, H. Sarvari, D. W. Chan, and M. Cristofaro, "Assessing the barriers and risks to private sector participation in infrastructure construction projects in developing countries of Middle East," *Sustainability*, vol. 13, no. 1, p. 153, 2020.

[9] N. S. Jayasena, D. W. Chan, and M. M. Kumaraswamy, "Is public–private partnership (PPP) a preferred strategy for procuring smart infrastructure in developed countries: an empirical study of the perceived benefits, barriers and recommended strategies," *Sustainability*, vol. 14, no. 11, p. 6421, 2022.

[10] H. Parkhouse, C. Y. Lu, and V. R. Massaro, "Multicultural Education Professional Development: A Review of the Literature," *Rev. Educ. Res.*, vol. 89, no. 3, pp. 416–458, Jun. 2019, doi: 10.3102/0034654319840359.

[11] C. R. Ahn, S. Lee, and F. Peña-Mora, "Application of Low-Cost Accelerometers for Measuring the Operational Efficiency of a Construction Equipment Fleet," *J. Comput. Civ. Eng.*, vol. 29, no. 2, p. 04014042, Mar. 2015, doi: 10.1061/(ASCE)CP.1943-5487.0000337.

[12] R. Y. Sunindijo and P. X. Zou, "An integrated framework for strategic safety management in construction and engineering," *Proc CIB W099 Achiev. Sustain. Constr. Health Saf. Lund Swed.*, pp. 63–742, 2014.

[13] A. C. Hurlimann, G. R. Browne, G. Warren-Myers, and V. Francis, "Barriers to climate change adaptation in the Australian construction industry–Impetus for regulatory reform," *Build. Environ.*, vol. 137, pp. 235–245, 2018.

[14] A. Redmond, A. Hore, M. Alshawi, and R. West, "Exploring how information exchanges can be enhanced through Cloud BIM," *Autom. Constr.*, vol. 24, pp. 175–183, 2012.

[15] T. Aziz, R. Begum, and G. Shah, "Assessment of Wheat Crop Water Productivity of Larkana District: A Remote Sensing Approach," *J. Asian Dev. Stud.*, vol. 13, no. 2, pp. 486–494, 2024.

[16] N. us Saqib, F. Saeed, and T. Aziz, "Effect Of Man-Made Structures On Natural Wetlands In Pakistan: A Case Study Of Chotiari Reservoir," *J. Clean WAS JCleanWAS*, vol. 6, no. 1, pp. 01–04, 2022.

[17] S. Besklubova, M. J. Skibniewski, and X. Zhang, "Factors Affecting 3D Printing Technology Adaptation in Construction," *J. Constr. Eng. Manag.*, vol. 147, no. 5, p. 04021026, May 2021, doi: 10.1061/(ASCE)CO.1943-7862.0002034.

[18] A. M. Jarkas and C. G. Bitar, "Factors Affecting Construction Labor Productivity in Kuwait," *J. Constr. Eng. Manag.*, vol. 138, no. 7, pp. 811–820, Jul. 2012, doi: 10.1061/(ASCE)CO.1943-7862.0000501.

[19] N. A. Karim, S. Hassan, J. Yunus, and M. Hashim, "Factors influence labour productivity and the impacts on construction industry," *Casp. J. Appl. Sci. Res.*, vol. 2, no. August, pp. 349–354, 2013.

[20] A. A. Zannah, A. A. Latiffi, A. U. Raji, A. A. Waziri, and U. Mohammed, "Causes of low-skilled workers' performance in construction projects," *Traektoriâ Nauki Path Sci.*, vol. 3, no. 6, pp. 4–1, 2017.

[21] D. D. Ahiaga-Dagbui, F. D. Fugar, J. W. McCarter, and E. Adinyira, "Potential risks to international joint ventures in developing economies: The Ghanaian construction industry experience," 2011, Accessed: Aug. 15, 2024. [Online]. Available: https://era.ed.ac.uk/handle/1842/5645

[22] S. A. Bello *et al.*, "Cloud computing in construction industry: Use cases, benefits and challenges," *Autom. Constr.*, vol. 122, p. 103441, 2021.

[23] M. S. Alnahari and S. T. Ariaratnam, "The application of blockchain technology to smart city infrastructure," *Smart Cities*, vol. 5, no. 3, pp. 979–993, 2022.

[24] J. Larsson, P. E. Eriksson, S. Lingegård, and A.-T. Järvenpää, "Innovation outcomes and processes in infrastructure projects – a comparative study of Design-Build and Design-Build-Maintenance contracts," *Constr. Manag. Econ.*, vol. 40, no. 2, pp. 142–156, Feb. 2022, doi: 10.1080/01446193.2021.2024864.

[25] S. Ratnasabapathy, A. Alashwal, and S. Perera, "Exploring the barriers for implementing waste trading practices in the construction industry in Australia," *Built Environ. Proj. Asset Manag.*, vol. 11, no. 4, pp. 559–576, 2021.

[26] E. L. Osabutey, K. Williams, and Y. A. Debrah, "The potential for technology and knowledge transfers between foreign and local firms: A study of the construction industry in Ghana," *J. World Bus.*, vol. 49, no. 4, pp. 560–571, 2014.

[27] J. J. Chen, "China's construction industry and foreign investment," *Build. Res. Inf.*, vol. 25, no. 1, pp. 5–10, Jan. 1997, doi: 10.1080/096132197370543.

[28] A. M. Odeh and H. T. Battaineh, "Causes of construction delay: traditional contracts," *Int. J. Proj. Manag.*, vol. 20, no. 1, pp. 67–73, 2002.

[29] F. Amin, K. I. A. Khan, F. Ullah, M. Alqurashi, and B. T. Alsulami, "Key Adoption Factors for Collaborative Technologies and Barriers to Information Management in Construction Supply Chains: A System Dynamics Approach," *Buildings*, vol. 12, no. 6, p. 766, 2022.

[30] A. Tezel, E. Papadonikolaki, I. Yitmen, and P. Hilletofth, "Preparing construction supply chains for blockchain technology: An investigation of its potential and future directions," *Front. Eng. Manag.*, vol. 7, no. 4, pp. 547–563, Dec. 2020, doi: 10.1007/s42524-020-0110-8.

[31] O. Lucon *et al.*, "Buildings climate change 2014: Mitigation of climate change. contribution of working group iii to the fifth assessment report of the intergovernmental panel on climate change," in *Intergovernmental Panel on Climate Change, Cambridge*, 2014.

[32] F. Ullah, S. M. Sepasgozar, M. J. Thaheem, and F. Al-Turjman, "Barriers to the digitalisation and innovation of Australian Smart Real Estate: A managerial perspective on the technology non-adoption," *Environ. Technol. Innov.*, vol. 22, p. 101527, 2021.

[33] E. M. Hassan, M. J. Memon (PhD), S. Sohu, M. A. Memon, and A. Hussain, "Factors Hindering The Endorsement Of Iso In Construction Industry Of Sindh," *Int. J. Disaster Recovery Bus. Contin.*, vol. 11, no. 01, Art. no. 01, Jun. 2020.

[34] A. Nwadike and S. Wilkinson, "Challenges facing building code compliance in New Zealand," *Int. J. Constr. Manag.*, vol. 22, no. 13, pp. 2493–2503, Oct. 2022, doi: 10.1080/15623599.2020.1801336.

[35] C. Preidel and A. Borrmann, "BIM-Based Code Compliance Checking," in *Building Information Modeling*, A. Borrmann, M. König, C. Koch, and J. Beetz, Eds., Cham: Springer International Publishing, 2018, pp. 367–381. doi: 10.1007/978-3-319-92862-3_22.

[36] D. D. Camacho *et al.*, "Applications of additive manufacturing in the construction industry–A forward-looking review," *Autom. Constr.*, vol. 89, pp. 110–119, 2018.

[37] M. Schneider, "Radio frequency identification (RFID) technology and its applications in the commercial construction industry," 2004, Accessed: Aug. 15, 2024. [Online]. Available: https://e-pub.uni-weimar.de/opus4/frontdoor/index/index/docId/106

[38] T. D. Akinosho *et al.*, "Deep learning in the construction industry: A review of present status and future innovations," *J. Build. Eng.*, vol. 32, p. 101827, 2020.

[39] A. Ahankoob, K. Manley, and B. Abbasnejad, "The role of contractors' building information modelling (BIM) experience in realising the potential values of BIM," *Int. J. Constr. Manag.*, vol. 22, no. 4, pp. 588–599, Mar. 2022, doi: 10.1080/15623599.2019.1639126.

[40] S. S. S. Gardezi, N. Shafiq, M. F. Nuruddin, S. A. Farhan, and U. A. Umar, "Challenges for implementation of building information modeling (BIM) in Malaysian construction industry," *Appl. Mech. Mater.*, vol. 567, pp. 559–564, 2014.

[41] I. Othman, Y. Y. Al-Ashmori, Y. Rahmawati, Y. M. Amran, and M. A. M. Al-Bared, "The level of building information modelling (BIM) implementation in Malaysia," *Ain Shams Eng. J.*, vol. 12, no. 1, pp. 455–463, 2021.

[42] A. R. B. Ibrahim, M. H. Roy, Z. Ahmed, and G. Imtiaz, "An investigation of the status of the Malaysian construction industry," *Benchmarking Int. J.*, vol. 17, no. 2, pp. 294–308, 2010.

[43] A. Okakpu, A. Ghaffarianhoseini, J. Tookey, J. Haar, A. Ghaffarianhoseini, and A. U. Rehman, "Risk factors that influence adoption of Building Information Modelling (BIM) for refurbishment of complex building projects: stakeholders perceptions," *Int. J. Constr. Manag.*, vol. 22, no. 13, pp. 2446–2458, Oct. 2022, doi: 10.1080/15623599.2020.1795985.

[44] E. V. Suprun and R. A. Stewart, "Construction innovation diffusion in the Russian Federation: Barriers, drivers and coping strategies," *Constr. Innov.*, vol. 15, no. 3, pp. 278–312, 2015.

[45] S. Durdyev, S. R. Mohandes, A. Mahdiyar, and S. Ismail, "What drives clients to purchase green building?: The cybernetic fuzzy analytic hierarchy process approach," *Eng. Constr. Archit. Manag.*, vol. 29, no. 10, pp. 4015–4039, 2022.

[46] R. Jin *et al.*, "A science mapping approach based review of construction safety research," *Saf. Sci.*, vol. 113, pp. 285–297, 2019.

[47] S. A. A. Shah, M. J. Memon, M. Hassan, W. M. Kalhoro, and M. Farooque, "Enhancing Building Information Modeling (BIM) Adoption in Pakistan: Challenges, Insights, And Practical Solutions," *Policy Res. J.*, vol. 3, no. 5, Art. no. 5, May 2025.

[48] P. Pandey and M. M. Pandey, *Research methodology tools and techniques*. Bridge Center, 2021. Accessed: Aug. 15, 2024.

[49] B. B. Adeyemi, "Reliability and Validity in Quantitative Research," in *Applied Linguistics and Language Education Research Methods: Fundamentals and Innovations*, IGI Global, 2024, pp. 86–102. Accessed: Aug. 15, 2024.

[50] J. Rose and C. W. Johnson, "Contextualizing reliability and validity in qualitative research: toward more rigorous and trustworthy qualitative social science in leisure research," *J. Leis. Res.*, vol. 51, no. 4, pp. 432–451, Aug. 2020, doi: 10.1080/00222216.2020.1722042.

[51] S. Sohu, A. H. Abdullah, S. Nagapan, A. A. Jhatial, K. Ullah, and I. A. Bhatti, "Significant Mitigation Measures for Critical Factors of Cost Overrun in Highway Projects of Pakistan.," *Eng. Technol. Appl. Sci. Res.*, vol. 8, no. 2, 2018,

[52] X. Chen *et al.*, "Implementation of technologies in the construction industry: a systematic review," *Eng. Constr. Archit. Manag.*, vol. 29, no. 8, pp. 3181–3209, 2022.

[53] N. S. Yiu, D. W. Chan, M. Shan, and N. N. Sze, "Implementation of safety management system in managing construction projects: Benefits and obstacles," *Saf. Sci.*, vol. 117, pp. 23–32, 2019.

[54] Z. Zhang, W. He, W. Li, and M. Abdous, "Cybersecurity awareness training programs: a cost–benefit analysis framework," *Ind. Manag. Data Syst.*, vol. 121, no. 3, pp. 613–636, 2021.

[55] A. Reiman *et al.*, "Safety Training Parks – Cooperative Contribution to Safety and Health Trainings," *Int. J. Constr. Educ. Res.*, vol. 15, no. 1, pp. 19–41, Jan. 2019, doi: 10.1080/15578771.2017.1325793.

[56] M. H. Memon, N. H. Abas, and S. Sohu, "Ranking the critical causes of accidents in construction projects of Sindh: Perspective of safety professionals," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1205, no. 1, p. 012035, Jun. 2023, doi: 10.1088/1755-1315/1205/1/012035.

[57] M. O. Sanni-Anibire, A. S. Mahmoud, M. A. Hassanain, and B. A. Salami, "A risk assessment approach for enhancing construction safety performance," *Saf. Sci.*, vol. 121, pp. 15–29, 2020.

[58] T. C. Haupt, M. Akinlolu, and M. T. Raliile, "Applications of digital technologies for health and safety management in construction," 2019.

[59] H. N. H. Al-Hashimy and J. Yao, "The moderating effect of internet of things and wearable technologies on enhancing safety management in construction sites," *Constr. Innov.*, 2025, Accessed: Jun. 24, 2025. [Online]. Available: https://www.emerald.com/insight/content/doi/10.1108/ci-10-2024-0318/full/html

[60] G. Saqib, M. U. Hassan, and M. U. Zubair, "Barriers to Incident Reporting in the Pakistani Construction Industry: An Exploratory Factor Analysis Approach," *J. Constr. Dev. Ctries.*, vol. 28, no. 2, Art. no. 2, 2023.

[61] Soomro, F. A., Memon, M. J., Chandio, A. F., Sohu, S., & Soomro, R. (2019). Causes of time overrun in construction of building projects in Pakistan. *Engineering, Technology & Applied Science Research*, *9*(1), 3762-3764.